Chiller VFD technology:
Efficiency Gains and Performance Metrics

Presented by

Larry Kouma

20 January 2006

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Agenda

- **Variable Frequency Drive Benefits**
  - Application characteristics
- **Application tools**
  - ARI 550/590 Standard
  - Review of full load and part load performance
- **Data Analysis**
- **Summary and Conclusions**

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System Basics

- Systems must be designed to accommodate the maximum or most severe conditions
- With few exceptions, most HVAC systems require modulation control and spend little time at most severe conditions

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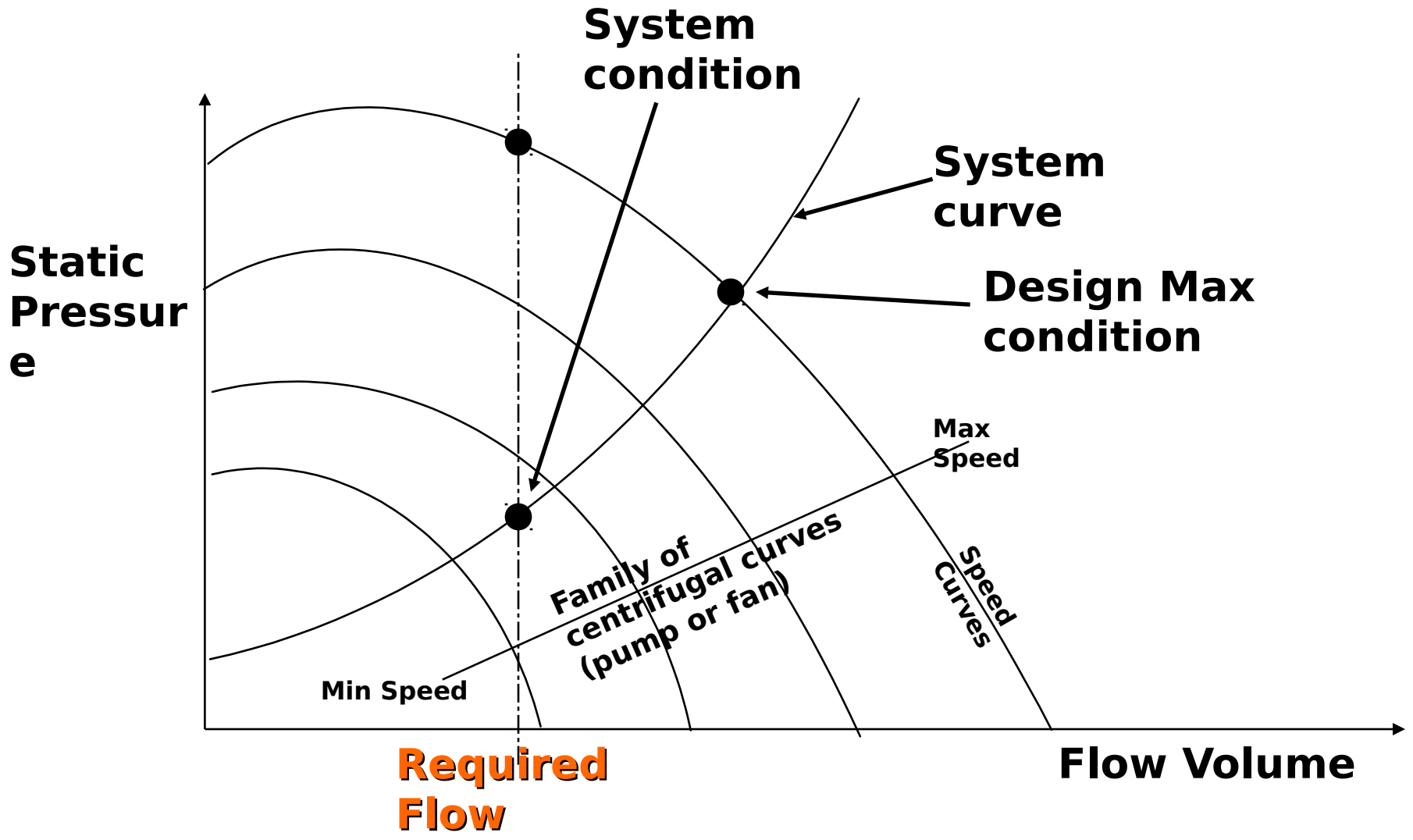
Centrifugal Performance Curves: Pump or Fan



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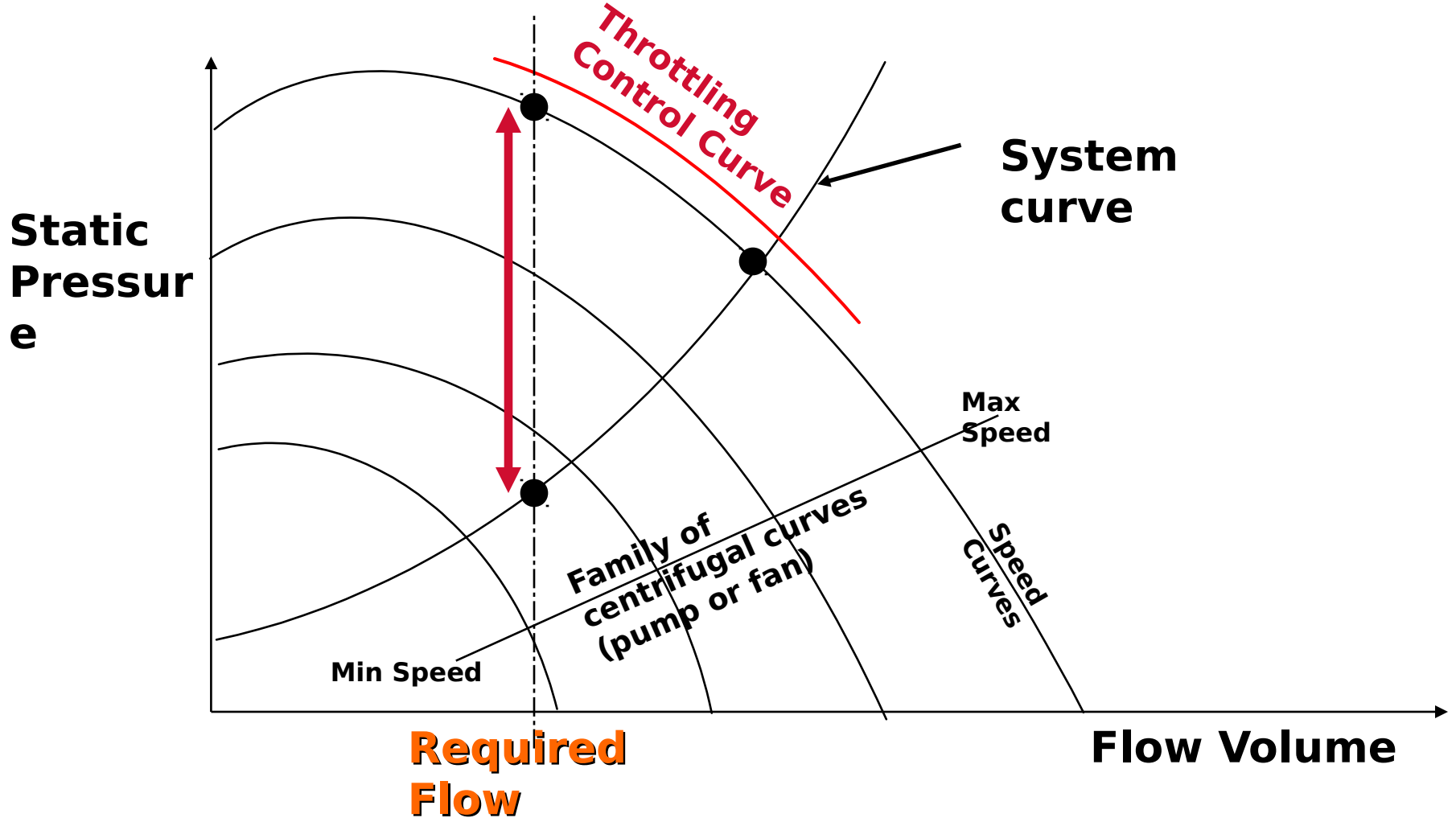

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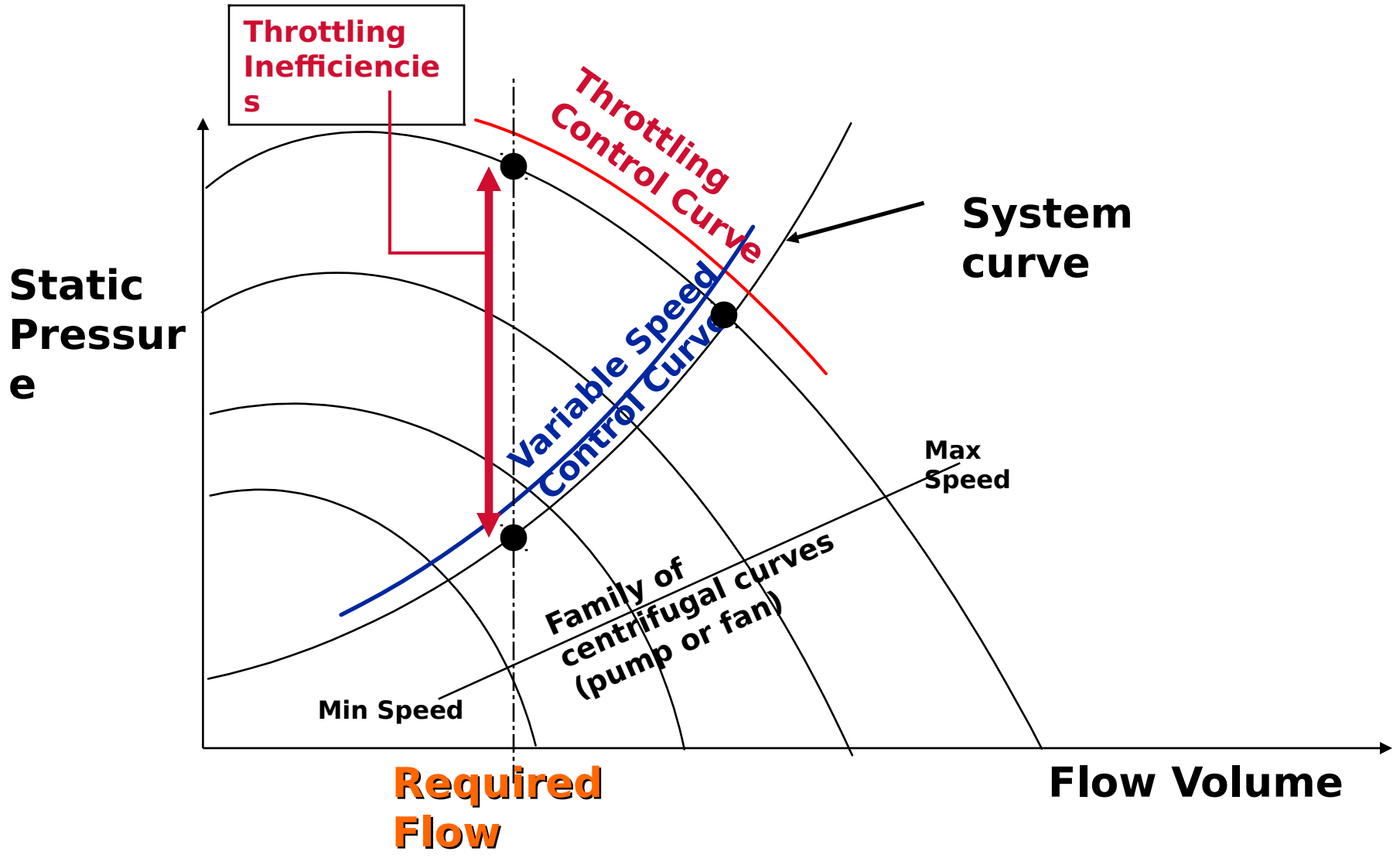
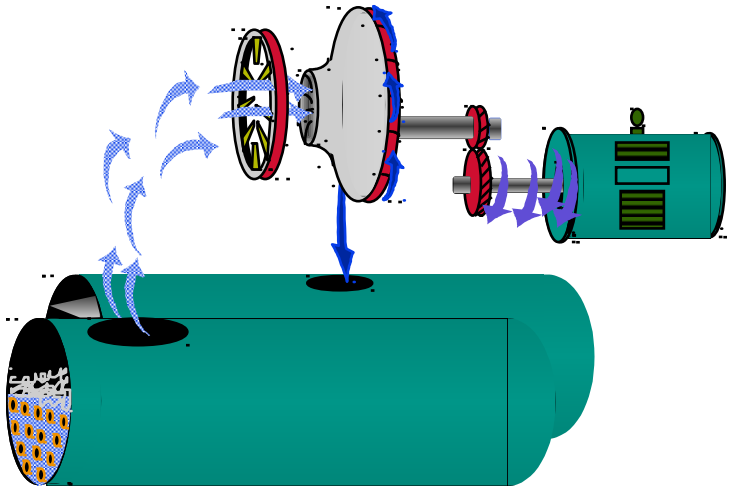


Constant Speed

Speed



PRV close as load decreases

Motor speed remains constant

Variable

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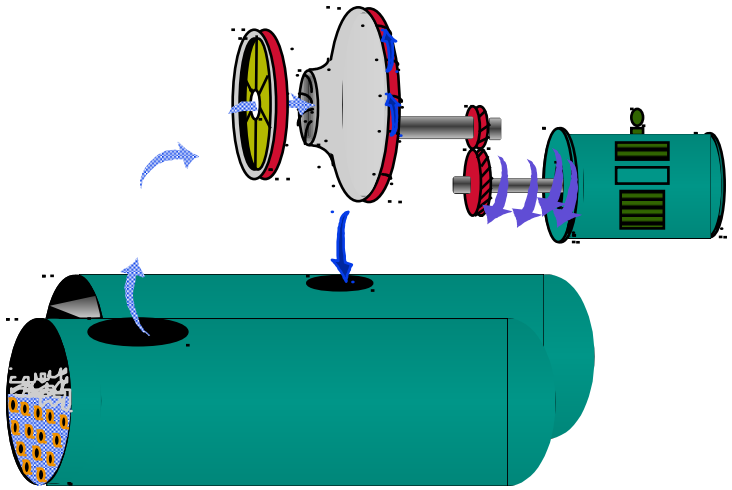
Constant Speed

Speed



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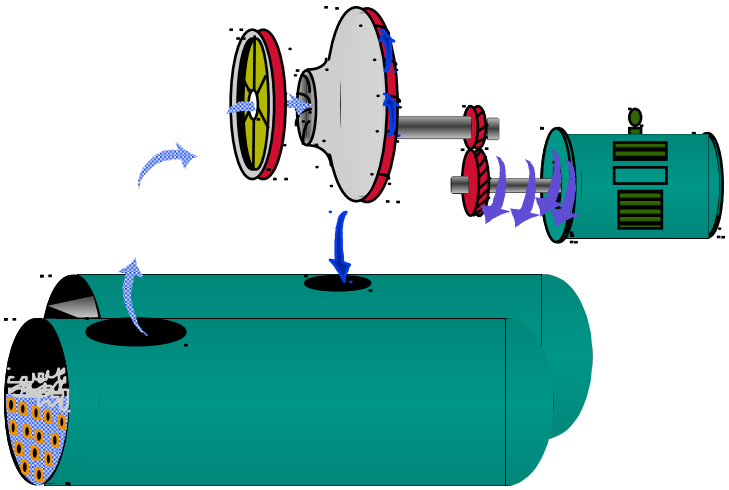

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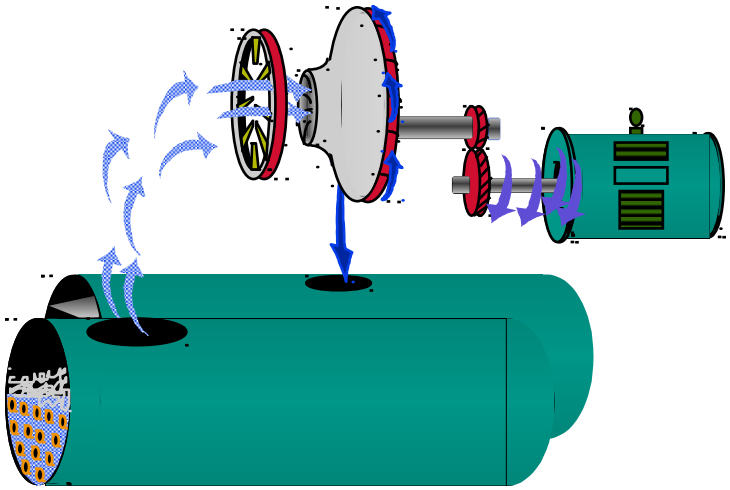

Adaptive Capacity Control logic

Optimizes compressor efficiency

Motor speed slows down

Optimizes PRV position

Consumes less energy

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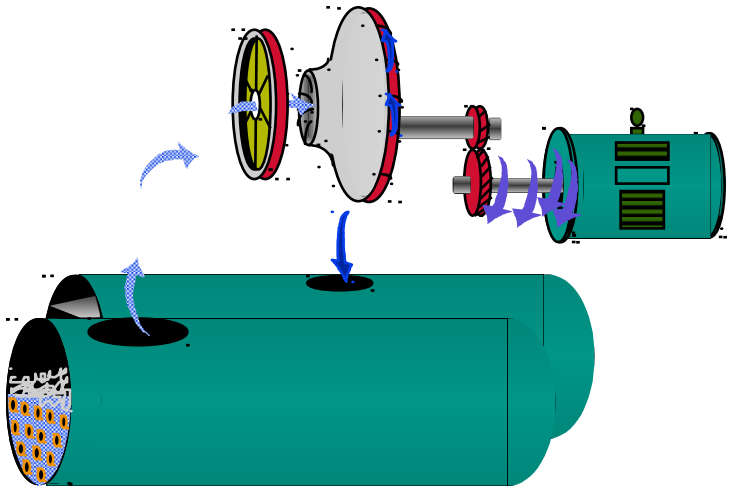
Constant Speed Speed



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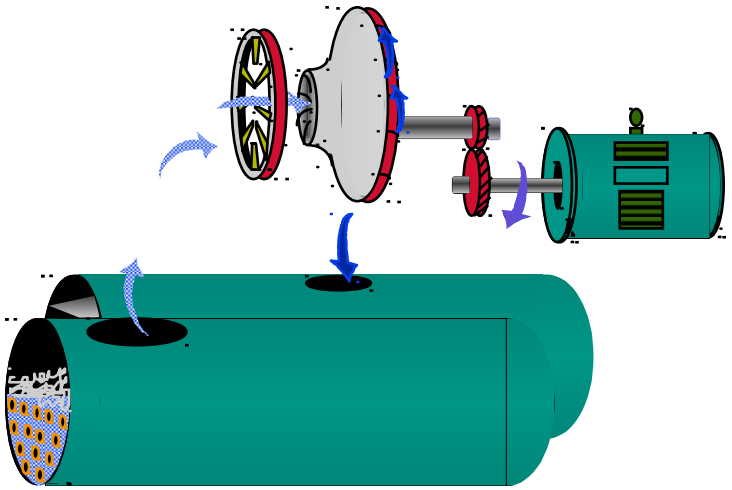

Adaptive Capacity Control logic

Optimizes compressor efficiency

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Technologies Application

- **Centrifugal**
- **Fan laws apply**

RPM ~ CFM

RPM^2 ~ Static Head

RPM^3 ~ horsepower

- **Savings driven by application head (p-disch minus p-suction) reduction**
- **Eliminate gas flow restriction**

% RPM		%HP
100		100
90	73	
75	42	
50	12	

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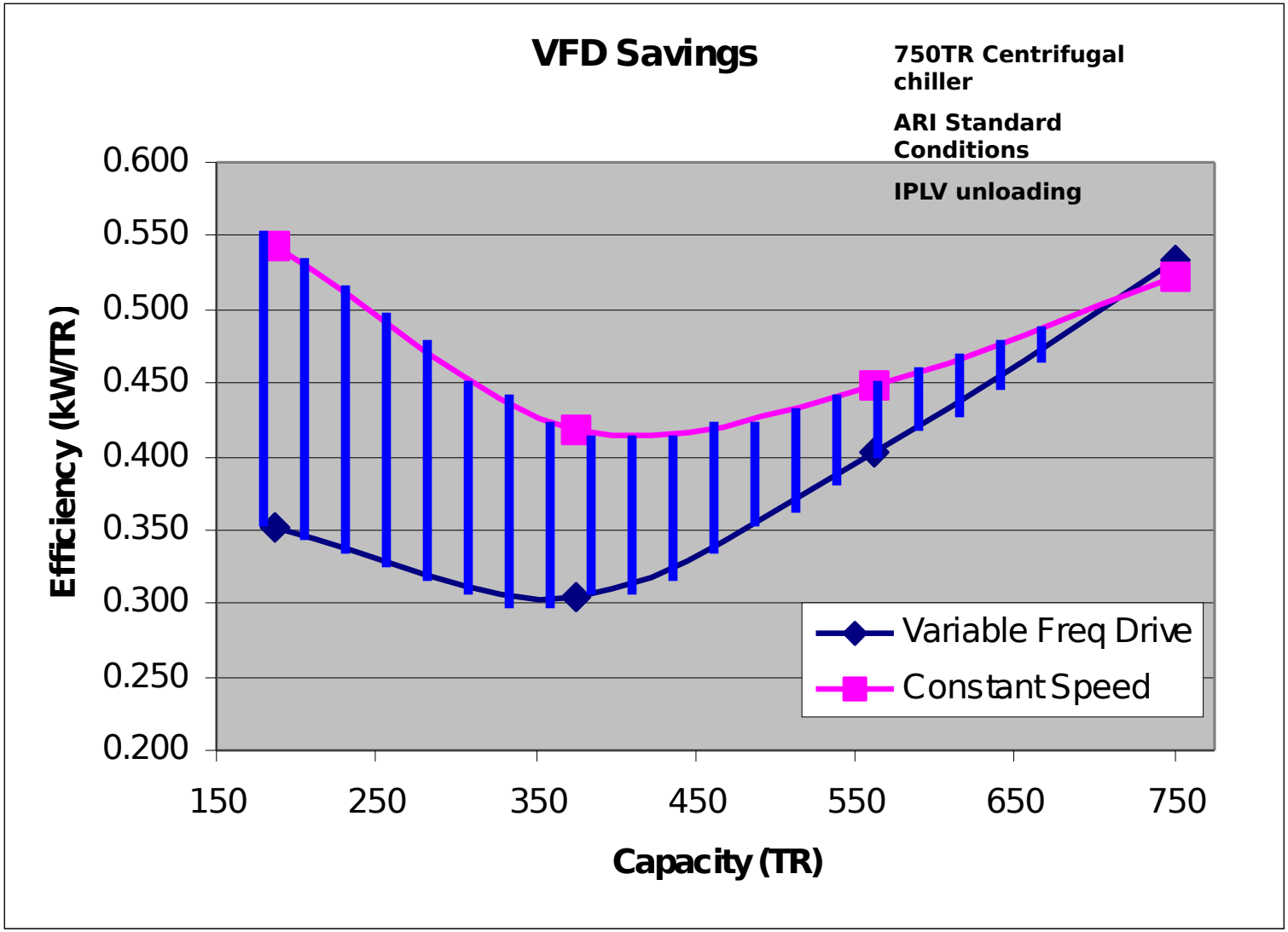

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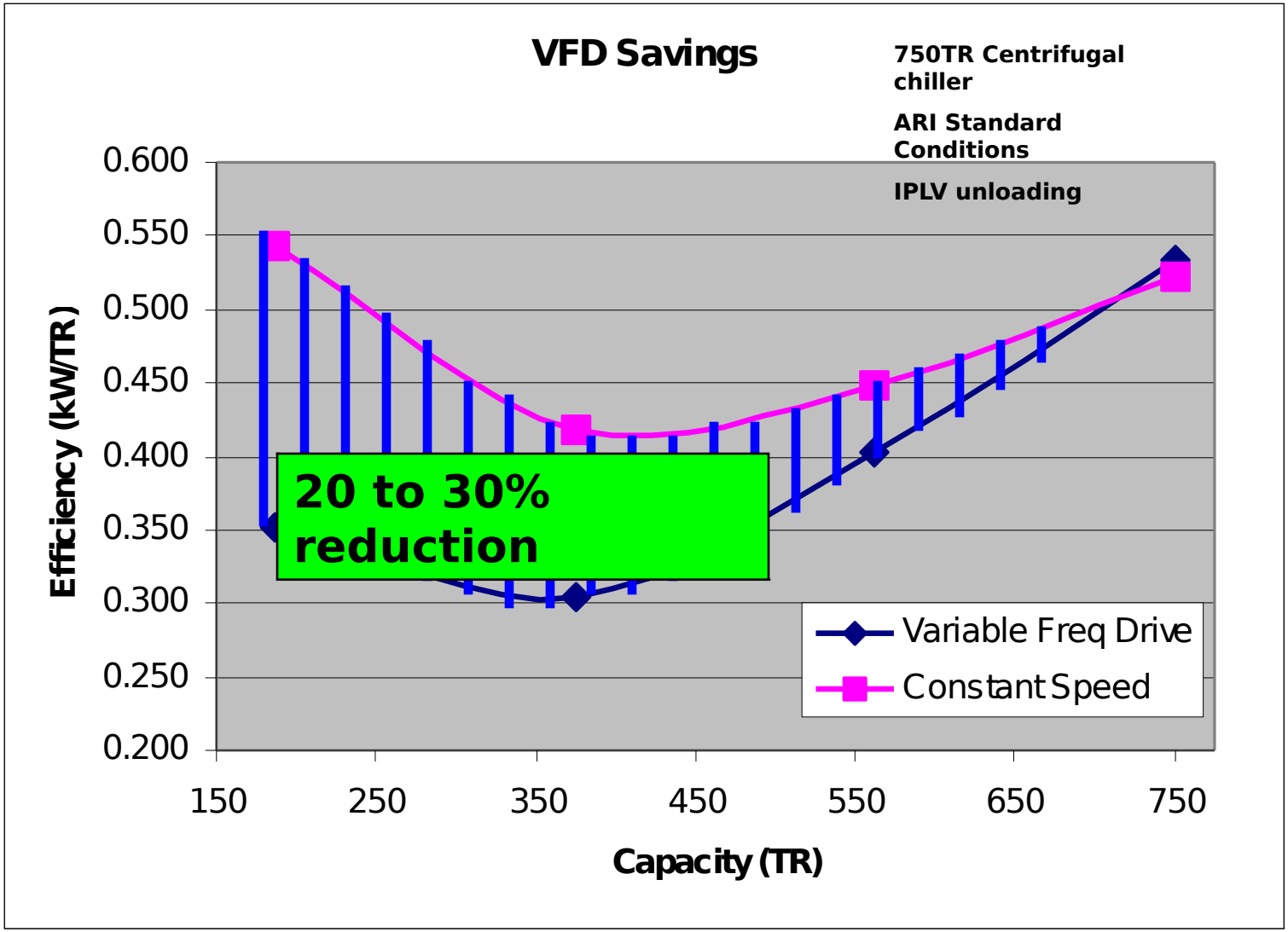
Technologies Application



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Proven VFD technology

- **Proven VFD savings**
- **Hundreds of articles, technical papers, and studies on VFD technology**
- **Savings on pumping applications by eliminating the “throttling” control for mass flow or pressure control**

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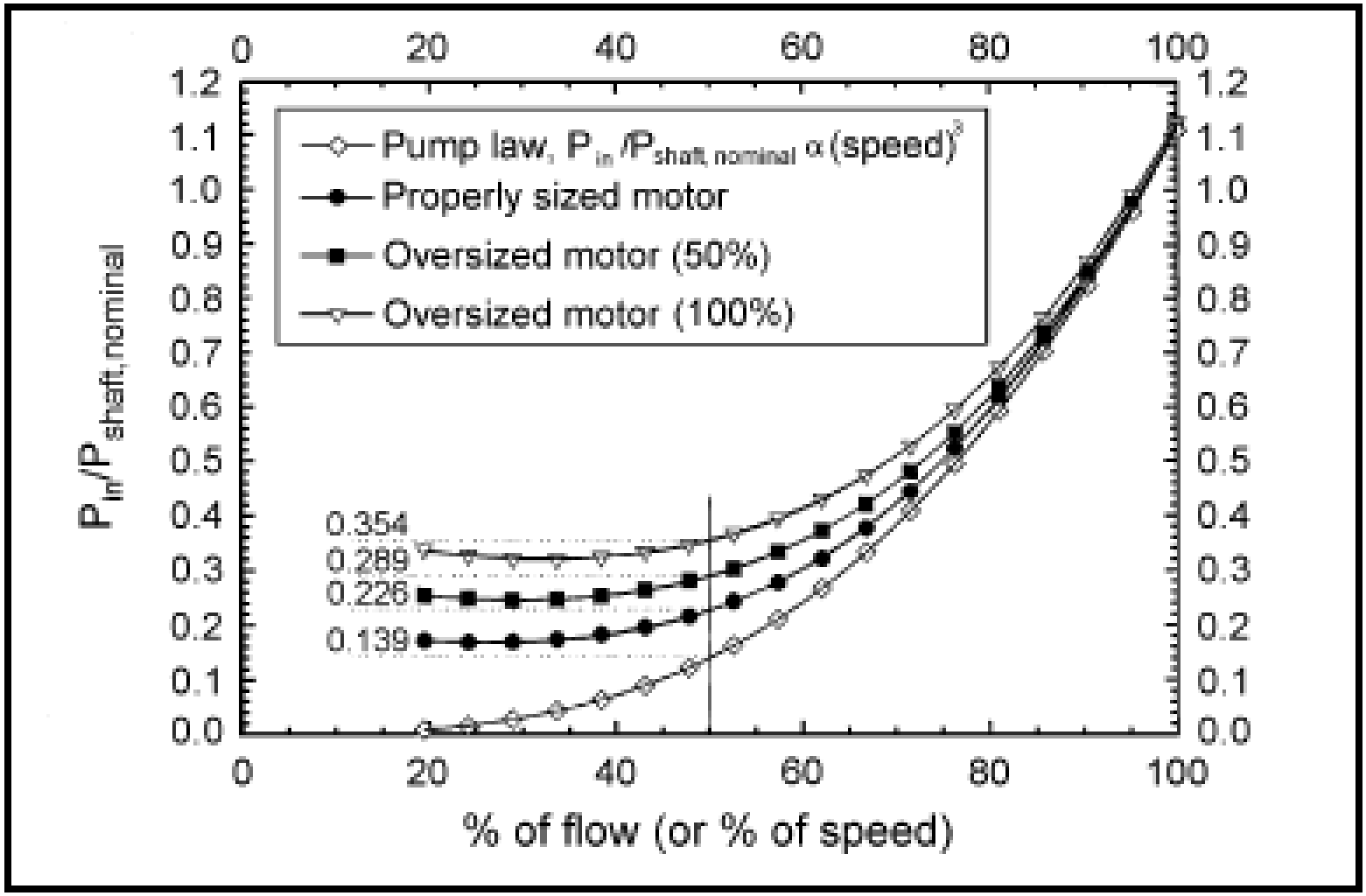
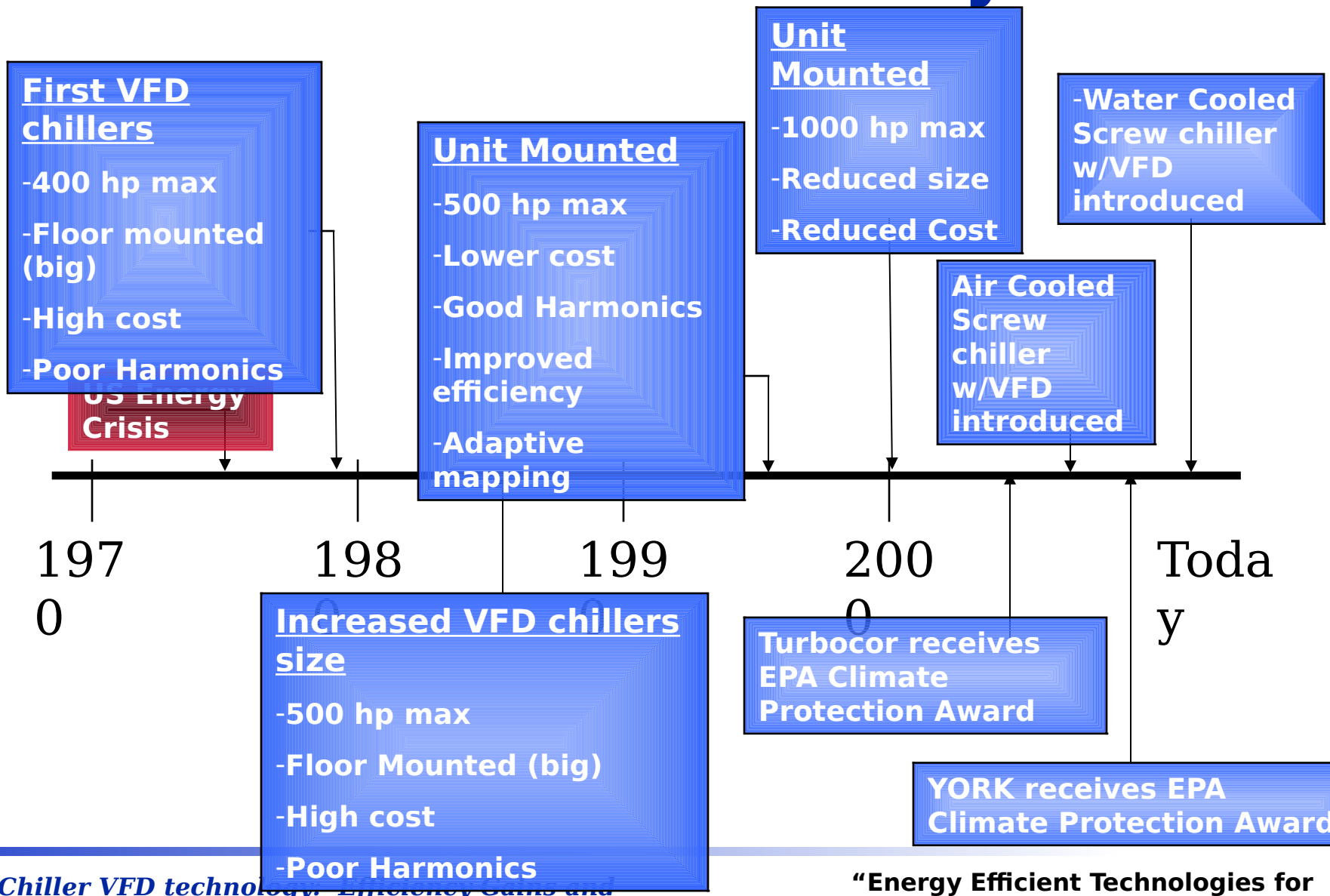


Figure 4: Non-dimensional pumping power as a function of % of flow for four different cases.

Reference: Bernier, M. and Bourret, B. “Pumping Energy and Variable Frequency Drives” ASHRAE Journal, December 1999

Water Chiller VFD history



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Technology Application

- **New Equipment OR Retrofits**
- **Centrifugal Compressors**
  - Variable displacement, head dependent
- **Screw Compressors**
  - Positive displacement, no surge issues
  - Savings directly related to capacity reduction
  - Maximize economizer benefit

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2005 EPA Climate Protection Award

Presented to York Int'l for the 1st Variable Speed Chillers

- **York Variable Speed Chillers save 400,000 tons of CO2 emissions annually. That is the equivalent of:**
  - 78,500 passenger cars not driven for one year

    or
  - 46,600 homes not powered by electricity for one year.

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Performance Metrics Developed

VFD Chiller Products today

- Proven Technology
- High Reliability
- Compact Packaging
- Affordable costs

Chillers traditionally evaluated based on full load design.

→ **This efficiency evaluation misses VFD energy savings benefits [reduced load and lift conditions]**

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→ **This efficiency evaluation misses VFD energy savings benefits [reduced load and lift conditions]**

Q: What can owners/engineers use to quantify VFD energy savings benefit?

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Performance Metrics Developed

ARI 550/590 Standard

"Performance Rating of Water-Chilling Packages Using the Vapor Compression Cycle"

- Integrated Part-Load Value [IPLV] metric was developed
- Recognized need for single average unit efficiency measure
- Metric similar to Season Energy Efficiency Ration [SEER] used for smaller DX products

- Metric introduced in 1986 and refined in following standard versions

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Performance Metrics Developed

ARI 550/590 Standard

"Performance Rating of Water-Chilling Packages Using the Vapor Compression Cycle"

Latest Version Considered:

- Conditions for 29 largest ARI Markets representing 80% of all chiller sales
- 24hr/7days and 12hr/5days operation
- Economized and non-economized systems
- Part load weighting based on weighted average ton-hours
- Building load profile varying with weather

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Application Tools IPLV

Result: Air Cooled

IPLV = 0.01A + 0.42B + 0.45C + 0.12D

where:
A = COP @ 100% load and 95 F ambient
B = COP @ 75% load and 80 F ambient
C = COP @ 50% load and 65 F ambient
D = COP @ 25% load and 55 F ambient

Note: IPLV is defined as operation specifically at ARI standard operating conditions. If conditions are non-standard, equation is represented as NPLV.

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Application Tools IPLV

Result: Water Cooled

$$\mathbf{IPLV} = \frac{\mathbf{1}}{\frac{\mathbf{1}}{\mathbf{0.01A}} + \frac{\mathbf{1}}{\mathbf{0.42B}} + \frac{\mathbf{1}}{\mathbf{0.45C}} + \frac{\mathbf{1}}{\mathbf{0.12D}}}$$

where:

A = kW/TR @ 100% load and 85 F ECWT
B = kW/TR @ 75% load and 75 F ECWT
C = kW/TR @ 50% load and 65 F ECWT
D = kW/TR @ 25% load and 65 F ECWT

Note: IPLV is defined as operation specifically at ARI standard operating conditions. If conditions are non-standard, equation is represented as NPLV.

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Application Tools IPLV

Two key variables overall chiller performance:

Load – Amount of cooling capacity required

Lift – Pressure differential compressor must overcome

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Application Tools IPLV

Two key variables overall chiller performance:

Load – Amount of cooling capacity required

Lift – Pressure differential compressor must overcome

Q: Which has greatest impact on efficiency?

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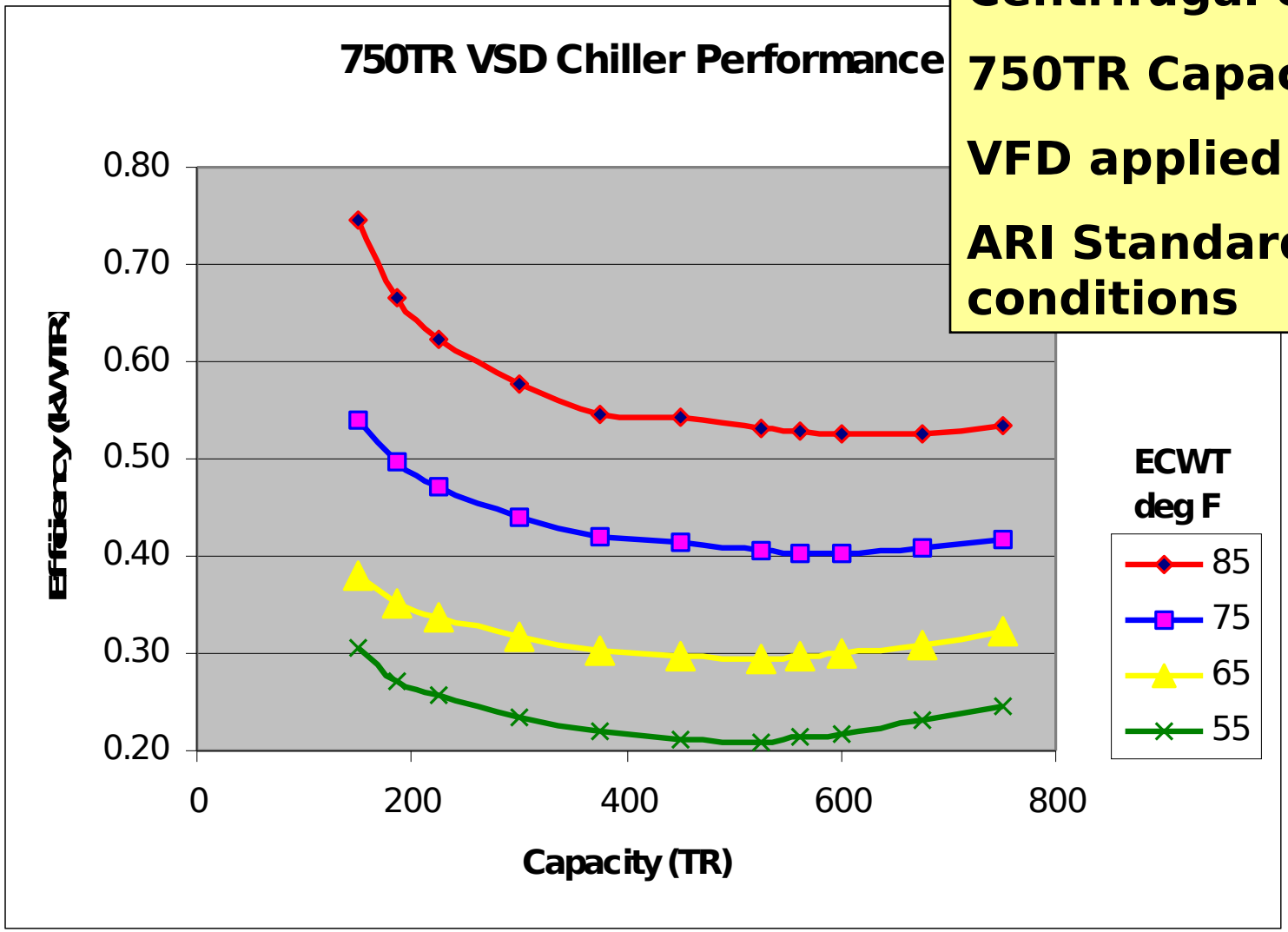
Load vs. Lift Effect

Water Cooled Centrifugal chiller

750TR Capacity

VFD applied

ARI Standard rating conditions



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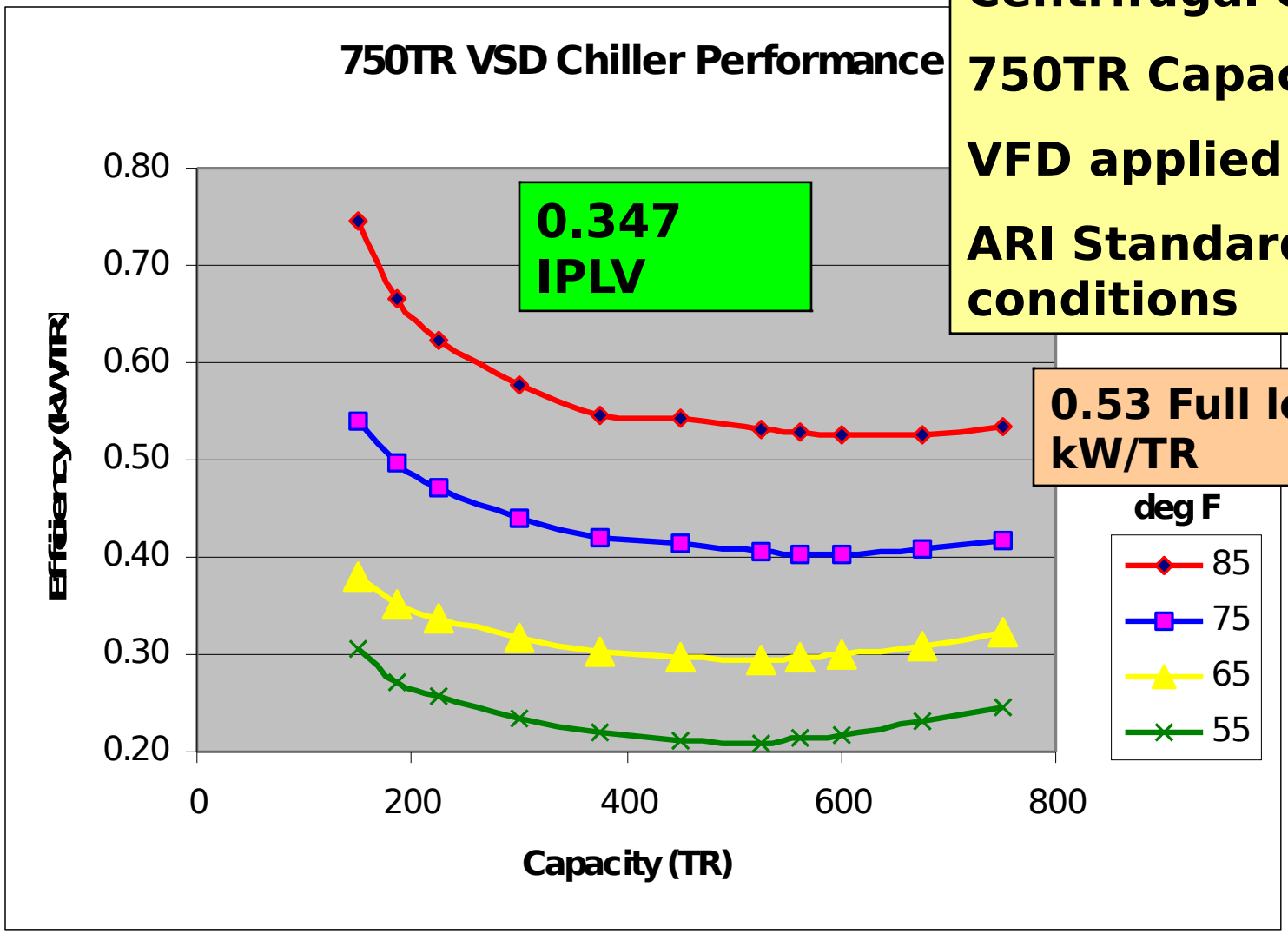

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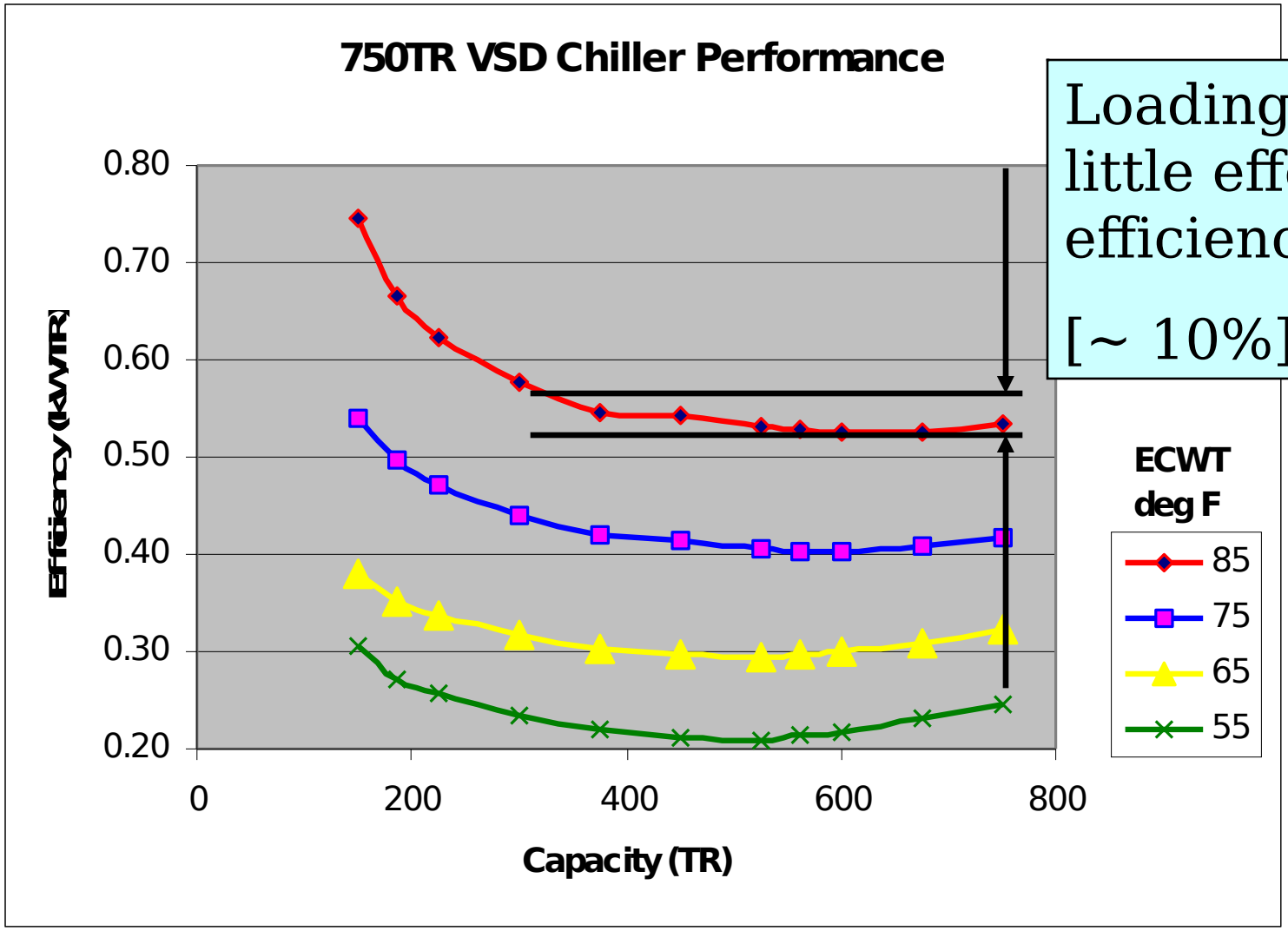

Loading has little effect on efficiency

[~ 10%]

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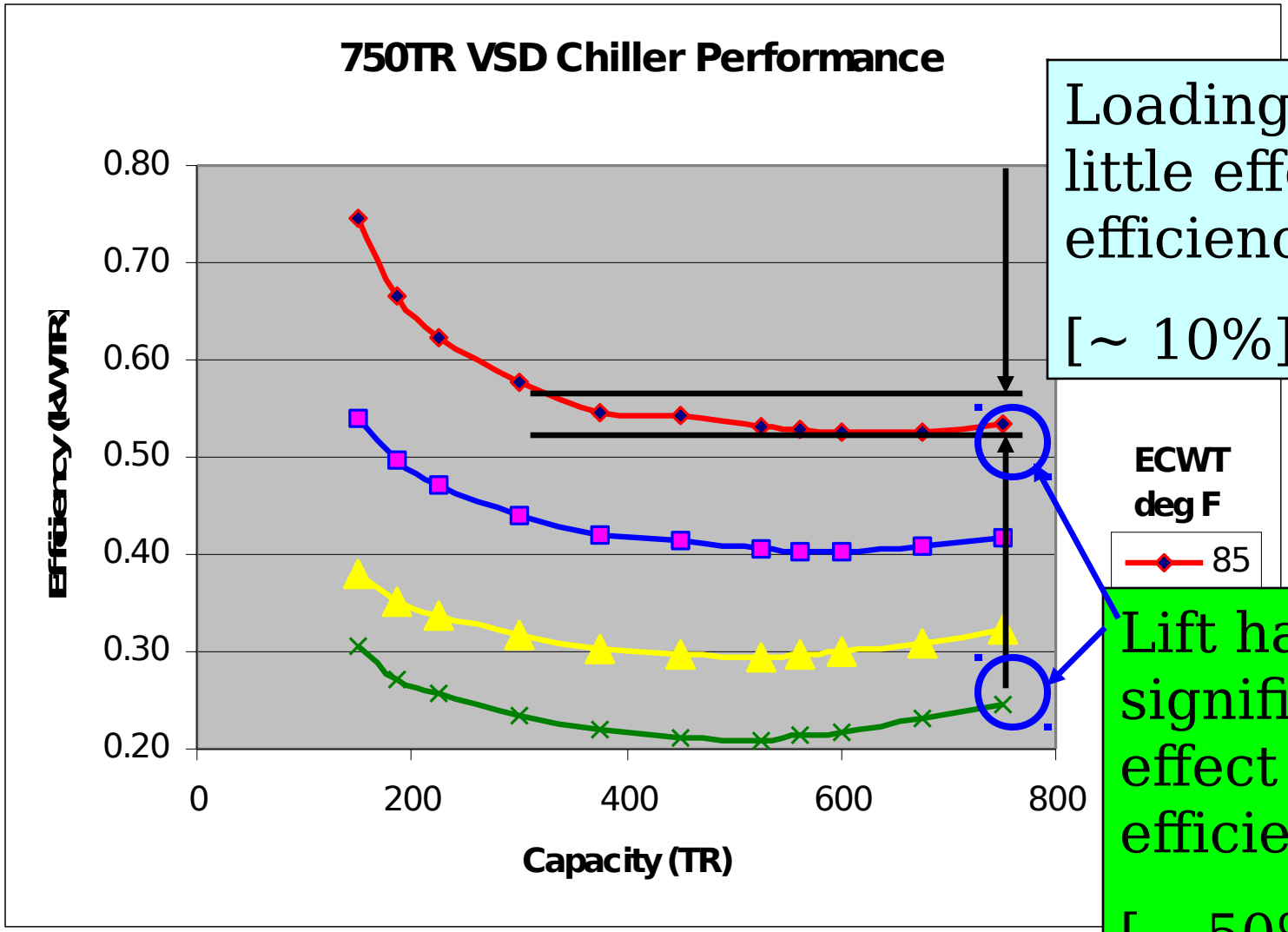
Load vs. Lift Effect



Loading has little effect on efficiency

[~ 10%]

Lift has significant effect on efficiency

[~ 50%]

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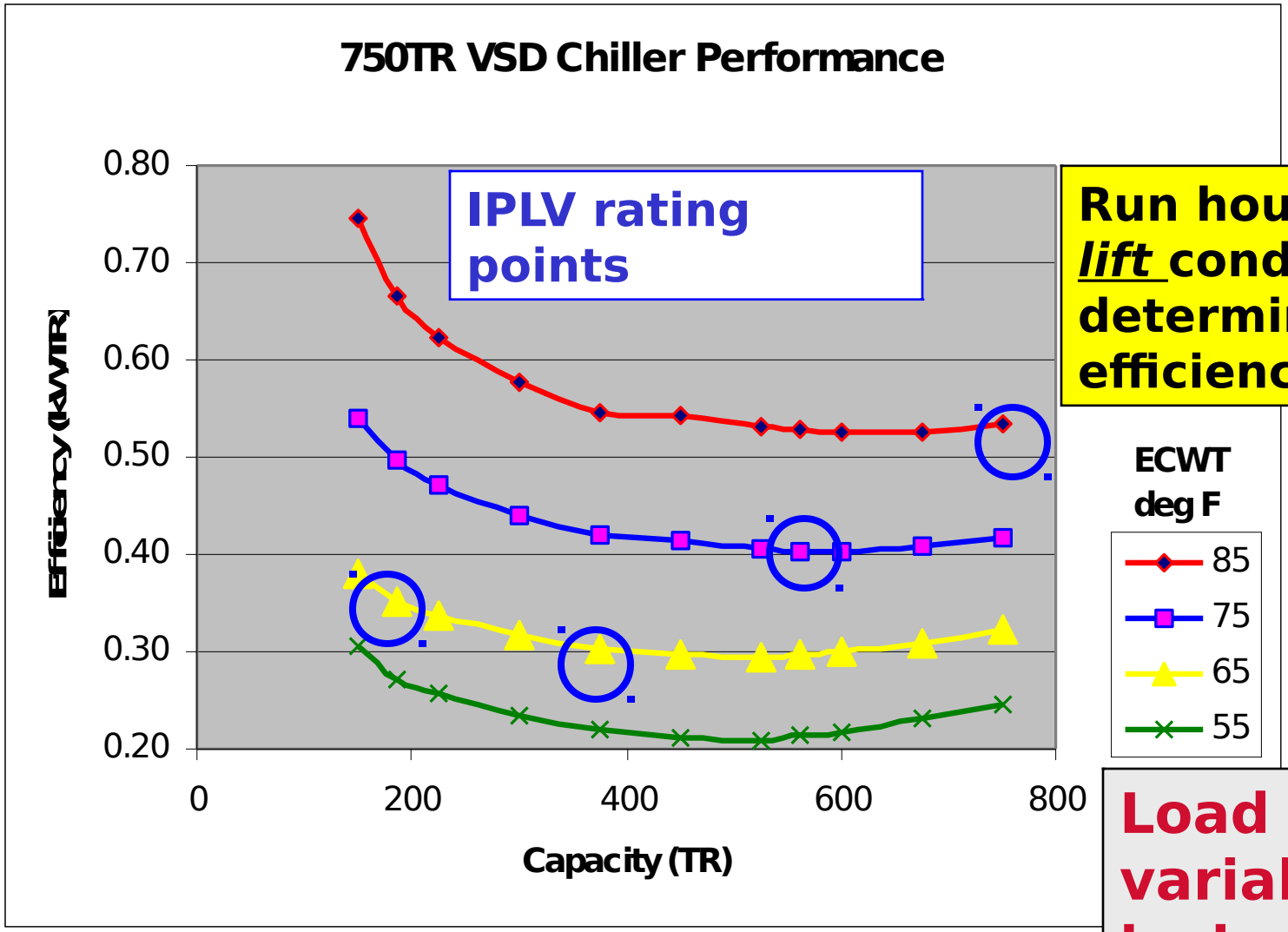
Load vs. Lift Effect



Run hours at each *lift* condition determine IPLV efficiency

Load variable insignificant!

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Effect of Lift

Sensitivity Check:

Reconfigure IPLV equation to consider efficiency heavily loaded chillers (multi-chiller plant)

$$\textbf{Modified IPLV} = \frac{1}{\frac{1}{0.01W} + \frac{1}{0.42X} + \frac{1}{0.45Y} + \frac{1}{0.12Z}}$$

where:

W = kW/TR @ 100% load and 85 F ECWT
X = kW/TR @ ***100%*** load and 75 F ECWT
Y = kW/TR @ ***100%*** load and 65 F ECWT
Z = kW/TR @ ***100%*** load and 65 F ECWT

Same equation for lift and weighted run hours, but normalize all ratings at 100% full load capacity

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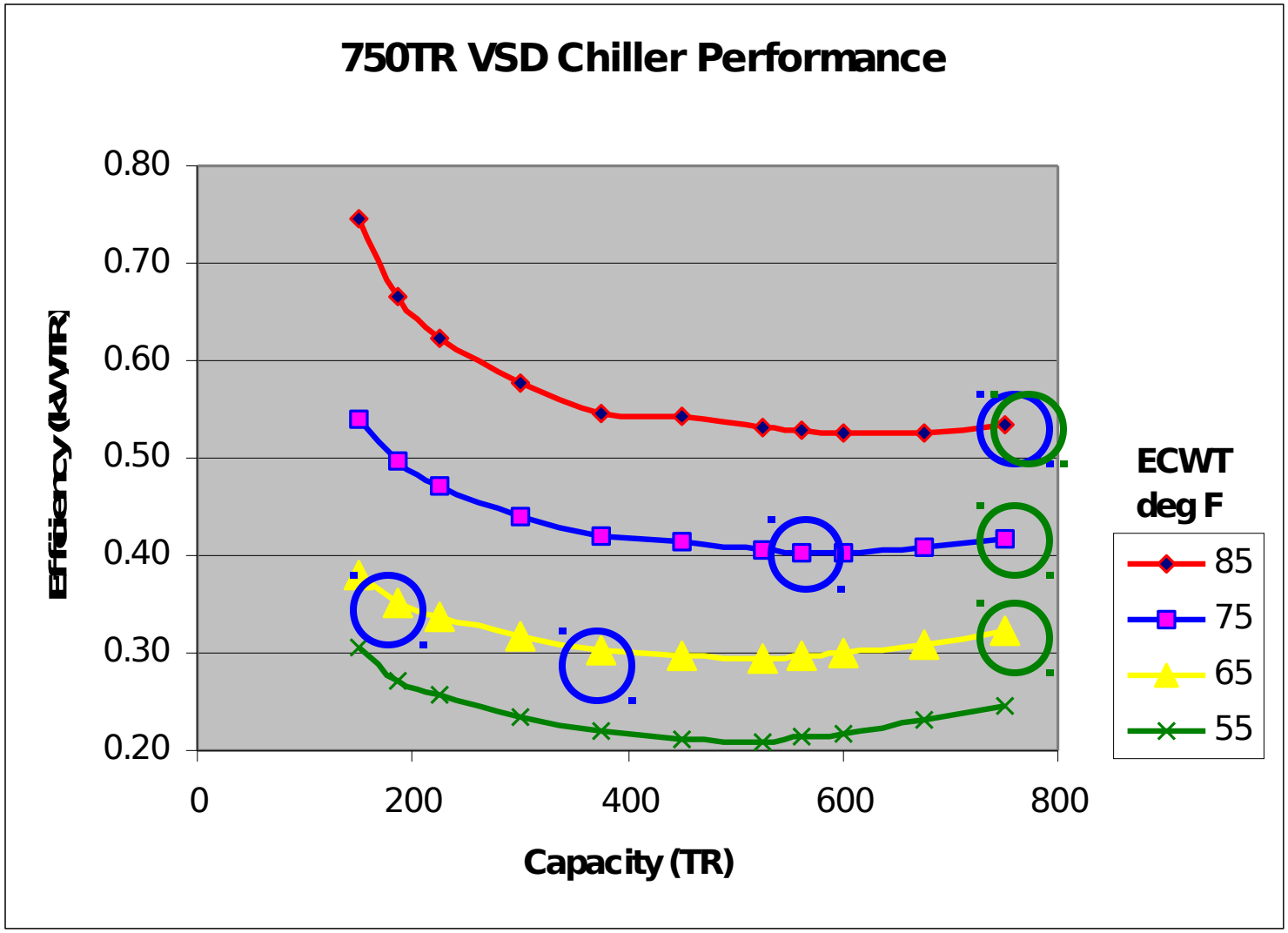
Load vs. Lift Effect



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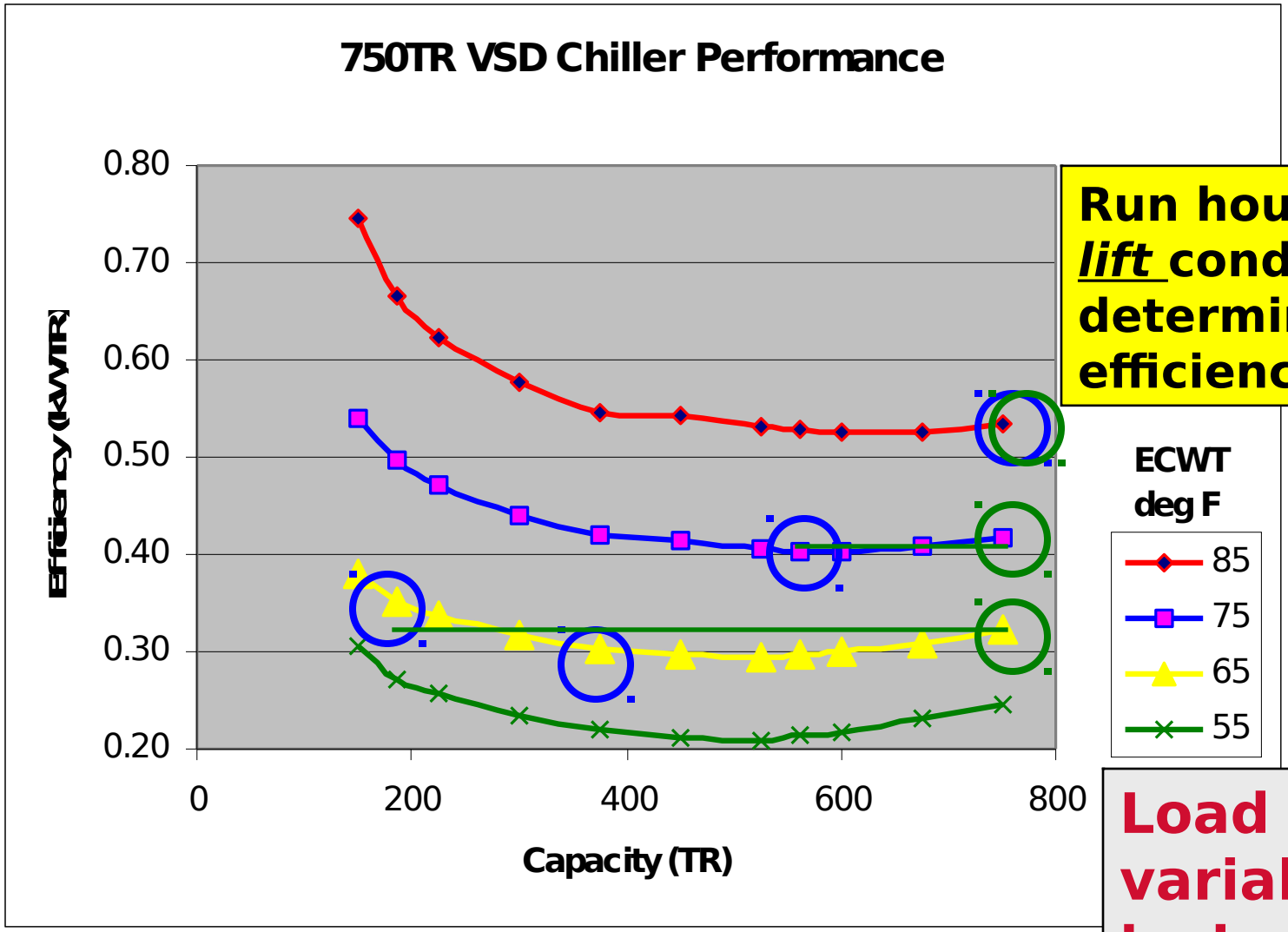

Run hours at each *lift* condition determine IPLV efficiency

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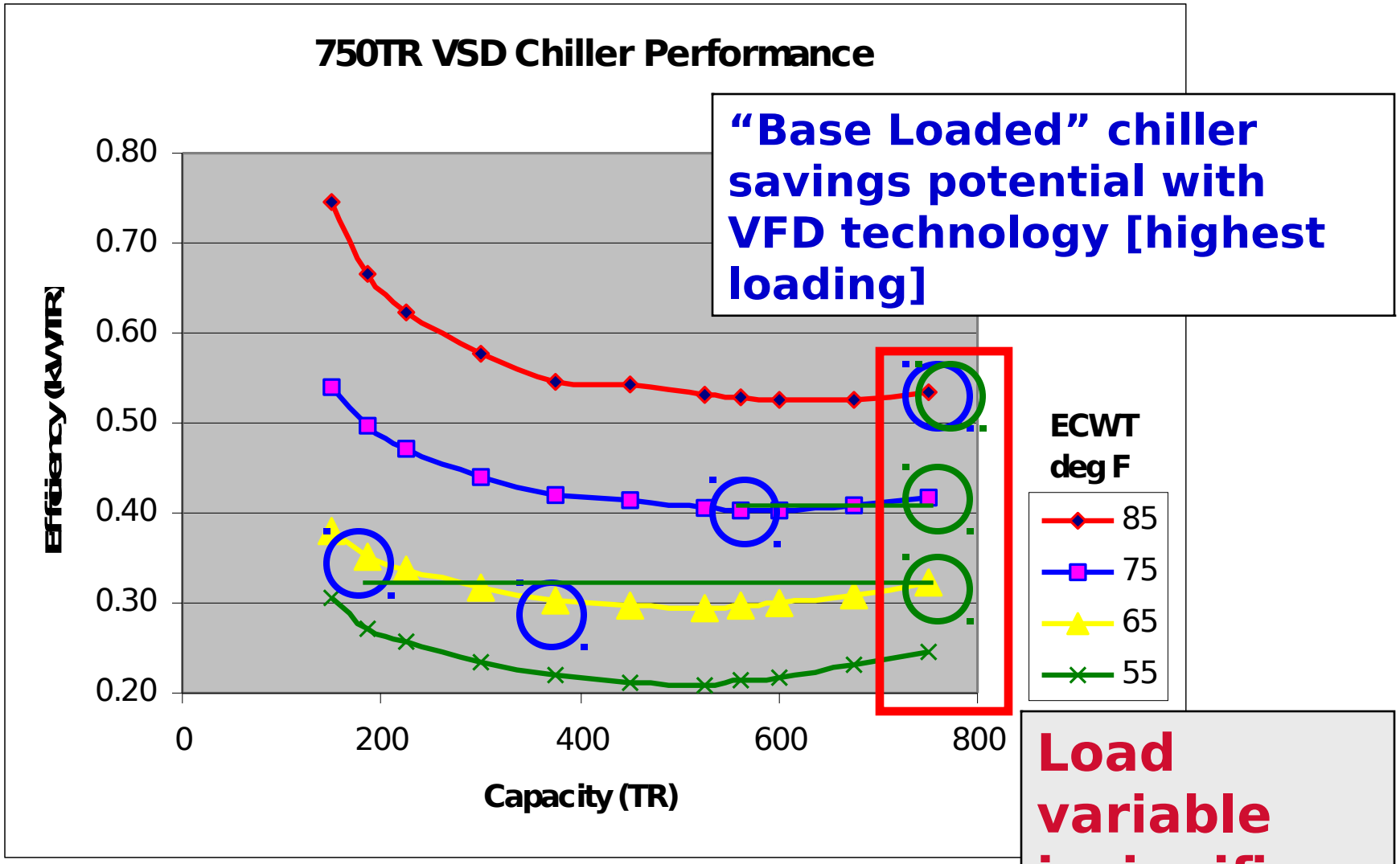
"Ener for Gove nd Retrofits"

Load vs. Lift Effect



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Load vs. Lift Effect

Sample 750TR Water Cooled VFD chiller:

Full load kW/TR: **0.53 kW/TR**
IPLV: **0.347**
Modified IPLV: **0.359**

IPLV
→ excellent indicator of overall chiller efficiency
→ predicted heavily loaded chiller efficiency within 3%

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Load vs. Lift Effect

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IPLV
→ excellent indicator of overall chiller efficiency
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Full Load kW/TR
→ VERY POOR indicator of overall chiller efficiency
→ predictor of heavily loaded chiller efficiency off 30%!

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Other model sizes surveyed with similar results:

Conclusions

VFD technology:

- **robust, reliable, cost effective, and proven to save energy**
- **reduced lift is the key -- harness power for fan laws for dramatic savings**
- **“base loaded” chillers benefit substantially from VFD technology**

IPLV metric:

- **reliable tool to determine relative water chiller efficiency**
- **reliable tool considering single chiller or multi chiller site**

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Thank You

ARI 550/590 Standard and accompanying white paper can be downloaded from www.ari.org for FREE!

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Drives at Full Load

- ✓ **Concern - Higher kW/ton at full load will have a negative impact on demand, increasing the use of inefficient peaking power plants**
- ✓ **Reality – Current generation of drives correct power factor to 0.95 or better**
- ✓ **Utilities actually see less demand (kVA) with improved power factor**

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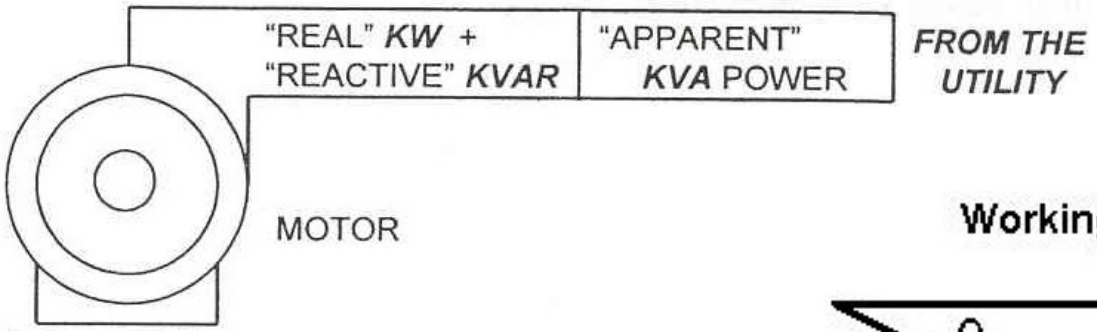
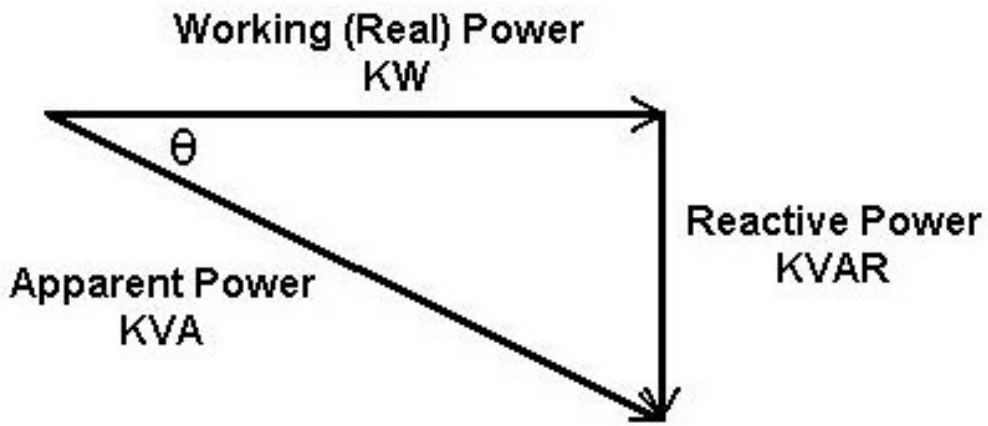
Power Factor: What is it?

A/C Loads





$$PF = \frac{Working\ Power}{Apparent\ Power} = \cos\theta$$

High PF = Lower Total Amps

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Power Factor and Amp Comparison

500 ton CS chiller, 0.576 kW/ton, PF = 0.89

Amps = (577 x 288 kW) / (460 volts x 0.89) = 406

Utility apparent power = 187 kVA

500 ton VSD chiller, 0.588 kW/ton, PF = 0.95

Amps = (577 x 294 kW) / (460 volts x 0.95) = 388

Utility apparent power = 178 kVA

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Utility apparent power = 178 kVA

Utility demand has dropped almost 5% with the

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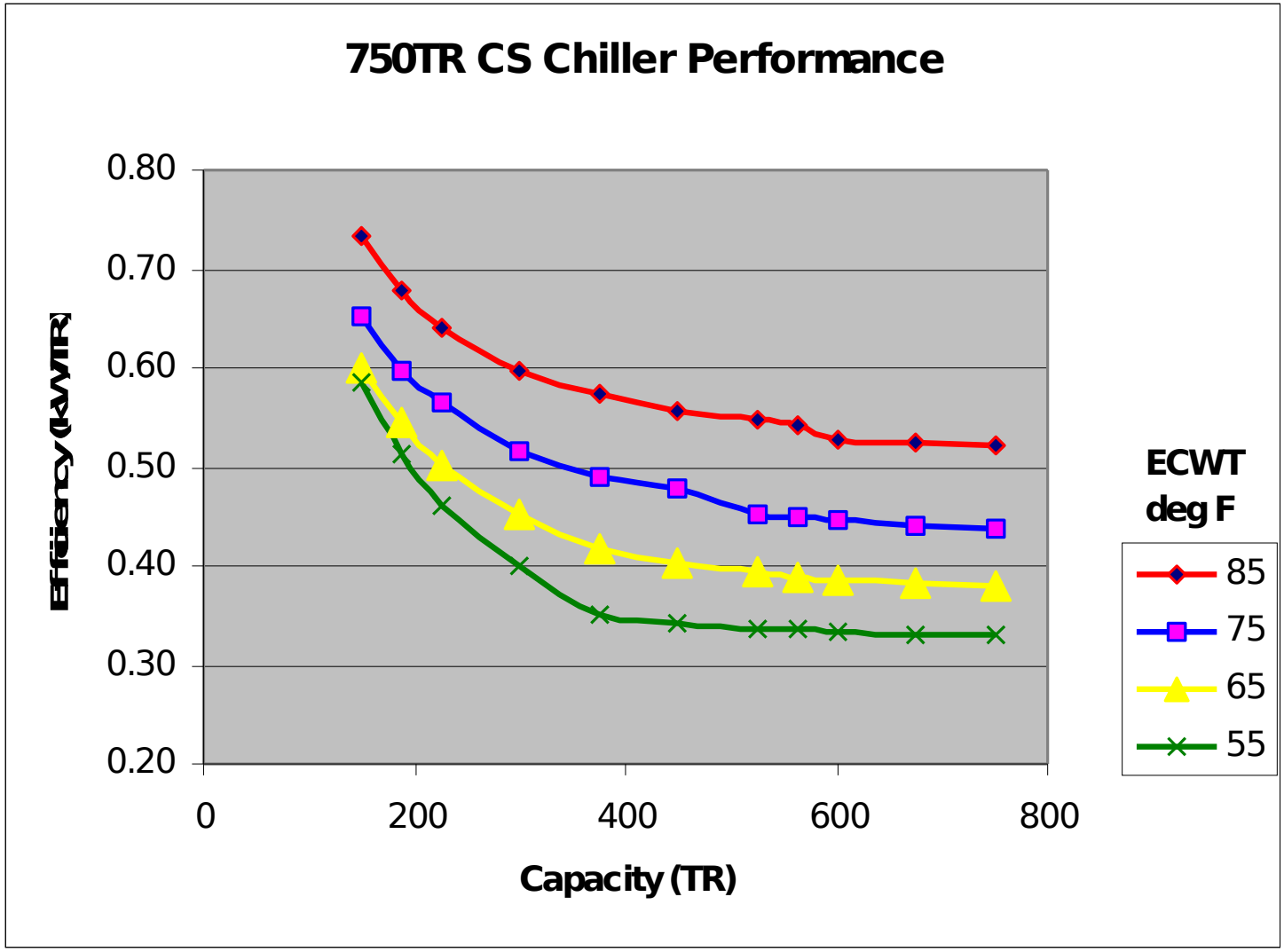

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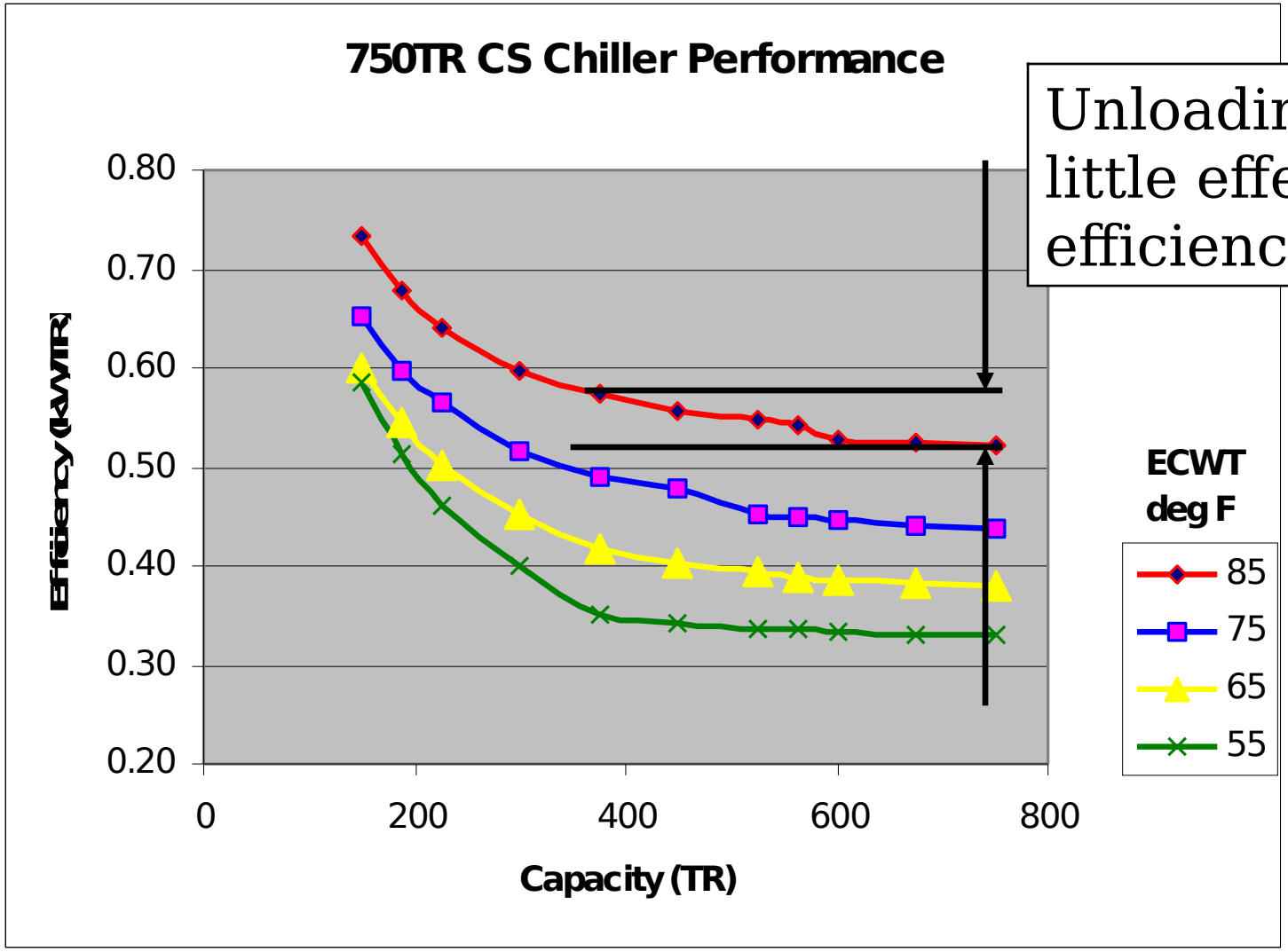

Unloading has little effect on efficiency

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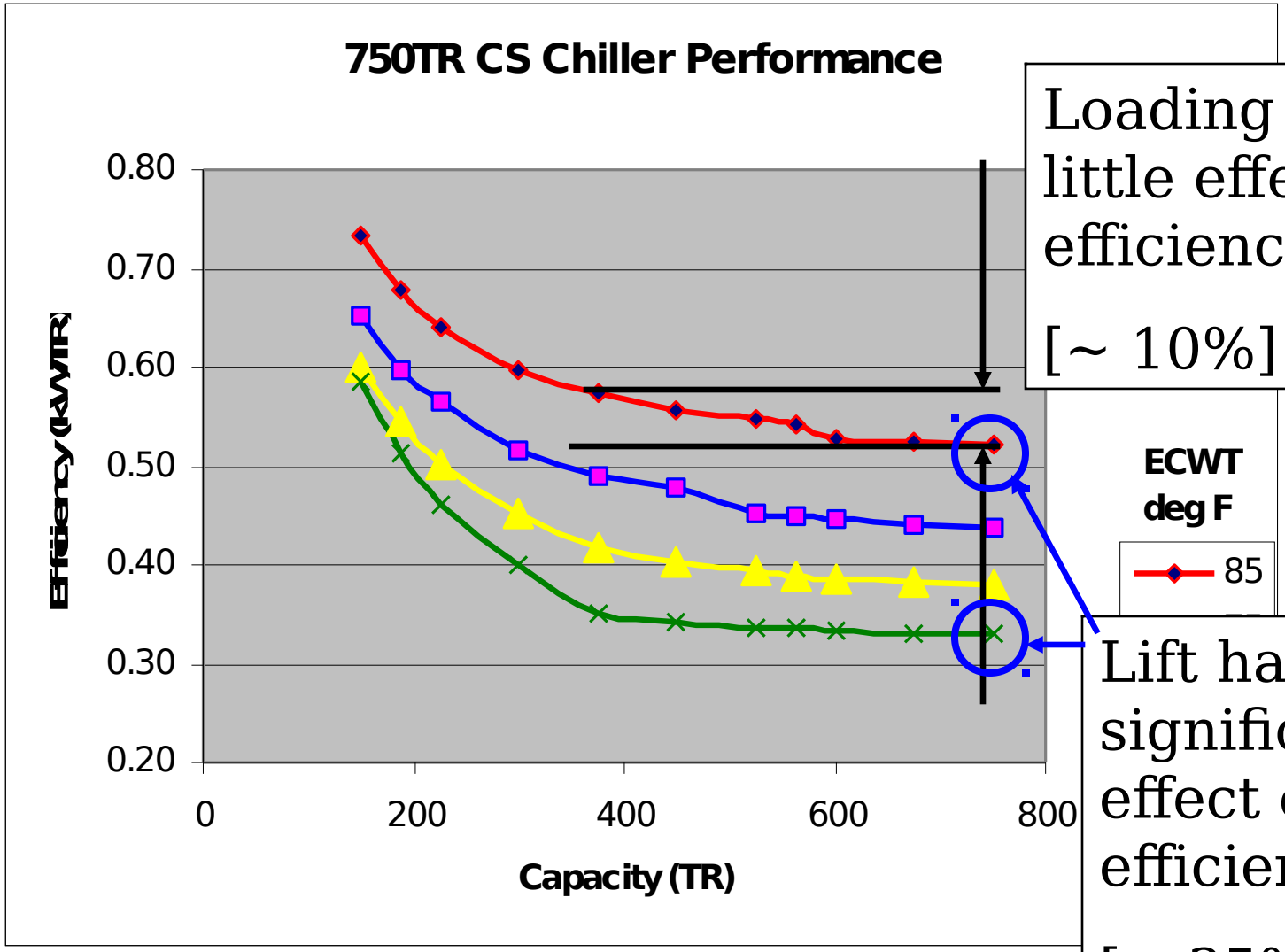
Load vs. Lift Effect



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[~ 10%]

Lift has significant effect on efficiency

[~ 35%]

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